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Risø National Laboratory, DK-4000 Roskilde, Denmark
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ENVIRONMENTAL RADIOACTIVITY IN GREENLAND IN 1982

A. Aarkrog, Henning Dahlgaard, Lars Hallstadius,
Elis Holm*, Heinz Hansen and J. Lippert

* University of Lund, Sweden

Abstract. Measurements of fallout radioactivity in Greenland in 1982 are reported. Strontium-90 (and Cesium-137 in most cases) was determined in samples of precipitation, sea water, vegetation, animals, and drinking water. Estimates are given of the mean contents of ^{90}Sr and ^{137}Cs in the human diet in Greenland in 1982. The report contains results from sampling expeditions to East Greenland as well as West Greenland waters in 1982. Brown algae collected in East Greenland in 1969 were analysed for ^{90}Sr.

INIS Descriptors

[0] DEER, DIET, ENVIRONMENT, EXPERIMENTAL DATA, FISHES, FOOD CHAINS, GLOBAL FALLOUT, GRAPHS, GREENLAND, PLANTS, RADIOACTIVITY, SEAWATER, SHEEP, TABLES
[1] ATMOSPHERIC PRECIPITATIONS, DRINKING WATER, STRONTIUM 90
[2] CESIUM 137, CESIUM 134
[3] ALGAE, AMERICIUM 241, PLUTONIUM 239, PLUTONIUM 240, SEDIMENTS

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CONTENTS

ABBREVIATIONS AND UNITS

J: joule: the unit of energy; 1 J = 1 Nm (= 0.239 cal)
Gy: gray: the unit of absorbed dose = 1 J kg^{-1} (= 100 rad)
Sv: sievert: the unit of dose equivalent = 1 J kg^{-1} (= 100 rem)
Bq: becquerel: the unit of radioactivity = 1 s^{-1} (= 27 pCi)

cal: calorie = 4.186 J
rad: 0.01 Gy
rem: 0.01 Sv
Ci: curie: $3.7 \cdot 10^{10}$ Bq (= $2.22 \cdot 10^{12}$ dpm)

T: tera: 10^{12}
G: giga: 10^{9}
M: mega: 10^{6}
m: milli: 10^{-3}
μ: mikro: 10^{-6}
n: nano: 10^{-9}
p: pico: 10^{-12}
f: femto: 10^{-15}
a: atto: 10^{-18}

cap: caput: (per individual)
TNT: trinitrotoluol; 1 Mt TNT: nuclear explosives equivalent to 10^{9} kg TNT.

cpm: counts per minute
dpm: disintegrations per minute
OR: observed ratio
CF: concentration factor
FP: fission products
μR: micro-roentgen, 10^{-6} roentgen
S.U.: pCi ^{90}Sr (g Ca)$^{-1}$
O.R.: observed ratio
M.U.: pCi ^{137}Cs (g K)$^{-1}$

V: vertebrae

m: male

f: female

nSr: natural (stable) Sr

eqv. mg KCl: equivalents mg KCl: activity as from 1 mg KCl (~ 0.88 dpm)

S.D.: standard deviation: $\sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{(n-1)}}$

S.E.: standard error: $\sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{n(n-1)}}$

U.C.L.: upper control level

L.C.L.: lower control level

S.S.D.: sum of squares of deviation: $\Sigma(\bar{x}-x_i)^2$

f: degrees of freedom

s^2: variance

v^2: ratio between the variance in question and the residual variance

P: probability fractile of the distribution in question

η: coefficient of variation, relative standard deviation

ANOVA: analysis of variance

A: relative standard deviation 20-33%

B: relative standard deviation >33%, such results are not considered significantly different from zero activity

B.D.L.: below detection limit

In the significance test the following symbols were used:

* : probably significant (P > 95%)

** : significant (P > 99%)

***: highly significant (P > 99.9%)

1. INTRODUCTION

1.1.

In 1982 the sampling programme was similar to that used in previous years but for a few minor modifications.

1.2.

As hitherto, samples were collected through the local district physicians and the head of the telestations. However, we have also obtained samples collected by the Royal Danish Navy and by the Fishery Investigations of Greenland (GFU). Finally, we performed two sample expeditions by ourselves to East Greenland in 1982.

1.3.

The estimated mean diet in Greenland was the same as that in 1962, i.e., it agreed with the estimate given by the late Professor E. Hoff-Jørgensen, Ph.D.

1.4.

The environmental studies in Greenland were carried out together with corresponding investigations in Denmark (cf. Risø Report No. 487[2]) and in the Faroes (cf. Risø Report No. 488[3]).

1.5.

The present report does not repeat information concerning sample collection and analysis already given in ref. 1.

1.6.

Appendix A contains the data from an expedition to Angmagssalik. In Appendix B the results of the Nella Dan cruise to East Greenland are presented. Appendix C shows the ^{90}Sr analysis of sea weed samples collected by GGU in 1969 at Scoresbysund and finally Appendix D gives the radiochemical procedure for the concentration of radiocesium from large volumes of sea water.

Our North Atlantic studies were supported by the Commission of the European Communities with funds from its Radiation Protection programme.

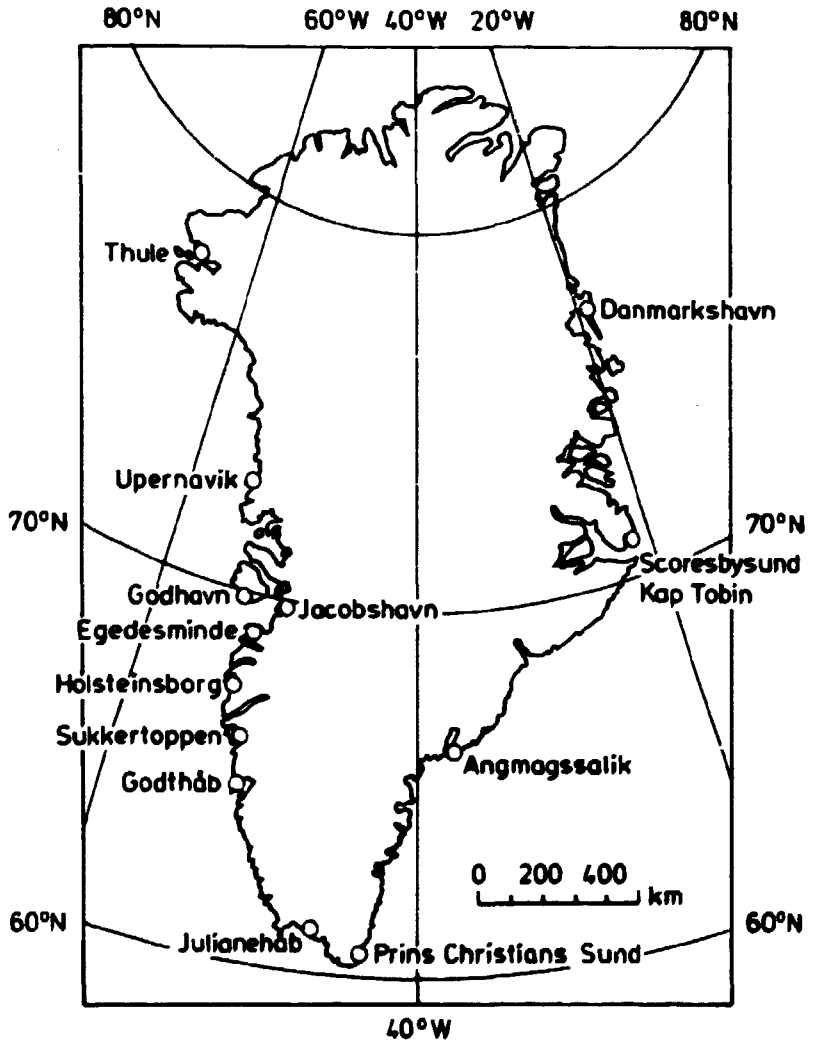

Fig. 1. Greenland.

2. RESULTS AND DISCUSSION

2.1. Strontium-90 in precipitation

Table 2.1.1 shows the results of the measurements.

The ^{90}Sr fallout in 1982 at the Greenland stations were approximately three times lower than in 1981. In Denmark[2] and the Faroes[3] the fallout decreased by a factor of 7 and 4, respectively.

Fig. 2.1 shows the accumulated ^{90}Sr at the various stations in Greenland, since measurements began in 1962.

Table 2.1.1. Strontium-90 in precipitation in Greenland in 1982. (Sampling area: 0.02 m^2)

Location m precipitation	Unit	Jan-March	April-June	July-Sept	Oct-Dec	1982
Upernavik	Bq m^{-3}	6.7	6.4	5.6 A	5.9 A	6.2
Σ 0.250	Bq m^{-2}	0.43	0.44	0.22 A	0.46 A	1.55
Godthåb	Bq m^{-3}	(4.3 B)	8.8	3.1	(3.7)	(4.2)
Σ 0.625	Bq m^{-2}	(0.77)	0.60	0.71	(0.55)	(2.63)
Prins Chr. Sund	Bq m^{-3}	7.1	5.5	2.5	(3.5)	(4.1)
Σ (1.55)	Bq m^{-2}	1.24	2.5	1.34	(1.29)	(6.37)
Scoresbysund	Bq m^{-3}	2.8	3.0		1.60	2.5
Σ 0.962	Bq m^{-2}	1.29	0.74		0.41	2.4
Danmarkshavn	Bq m^{-3}	8.7	18.8	53	14.8	15.2
Σ 0.132	Bq m^{-2}	0.58	0.51	0.47	0.45	2.0

Figures in brackets were estimated from the anova: VAR3.

Table 2.1.2. Fallout rates and a cumulated fallout (Bq m^{-2}) in Greenland 1950-1982

	Scoresbysund (Kap Tobin)		Pr.Chr.Sund		Godthåb		Upernavik	
	di	Ai(29)	di	Ai(29)	di	Ai(29)	di	Ai(29)
1950	0.37	0.36	2.04	1.99	0.57	0.56	0.20	0.20
1951	1.76	2.06	9.79	11.50	2.77	3.25	0.97	1.14
1952	3.44	5.38	19.19	29.97	5.42	8.46	1.90	2.97
1953	8.70	13.74	48.47	76.59	13.69	21.63	4.81	7.60
1954	33.06	45.69	184.28	254.71	52.05	71.94	18.29	25.28
1955	43.49	87.08	242.45	485.41	68.48	137.10	24.06	48.17
1956	53.93	137.67	300.61	767.46	84.91	216.76	29.83	76.16
1957	53.93	187.08	300.61	1042.85	84.91	294.54	29.83	103.49
1958	74.81	255.70	417.04	1425.40	117.79	402.59	41.39	141.45
1959	106.11	353.27	591.53	1969.29	167.07	556.21	58.70	195.43
1960	19.82	364.28	110.51	2030.68	31.21	573.55	10.97	201.52
1961	25.75	380.83	143.57	2122.90	40.55	599.60	14.25	210.67
1962	129.17	497.95	720.07	2775.83	203.38	784.01	71.46	275.46
1963	290.45	769.78	1545.12	4218.89	475.45	1229.72	160.58	425.75
1964	180.93	928.26	929.07	5026.38	258.63	1453.19	100.27	513.59
1965	68.82	973.53	383.32	5281.93	166.50	1581.44	38.11	538.67
1966	37.37	987.02	207.94	5360.21	43.29	1586.36	20.72	546.18
1967	18.13	981.41	73.63	5305.51	32.56	1580.68	12.21	545.20
1968	24.42	982.08	136.16	5313.15	37.00	1579.48	13.32	545.33
1969	18.13	976.59	72.89	5258.83	22.20	1563.85	6.73	539.03
1970	33.30	986.03	59.20	5192.43	34.41	1560.51	12.58	538.58
1971	15.17	977.56	122.84	5189.73	32.56	1555.44	8.14	533.81
1972	12.58	966.75	55.50	5121.35	15.17	1533.52	4.07	525.17
1973	3.40	947.24	17.91	5017.88	6.92	1504.06	2.78	515.48
1974	12.21	936.79	45.88	4944.16	19.83	1486.92	13.14	516.13
1975	4.48	919.04	86.21	4911.57	19.57	1470.91	8.44	512.18
1976	3.00	900.26	11.17	4806.47	4.85	1440.91	2.44	502.46
1977	5.18	884.06	34.78	4726.91	14.06	1420.60	7.03	497.46
1978	10.36	873.29	54.39	4668.38	14.43	1401.14	7.77	493.30
1979	2.81	855.41	10.36	4568.24	9.99	1377.80	3.70	485.26
1980	3.15	838.28	7.03	4467.21	4.74	1349.89	3.70	477.41
1981	5.51	823.86	34.04	4394.94	12.95	1330.65	5.55	471.55
1982	2.41	806.75	6.36	4297.35	2.63	1301.79	1.55	461.93

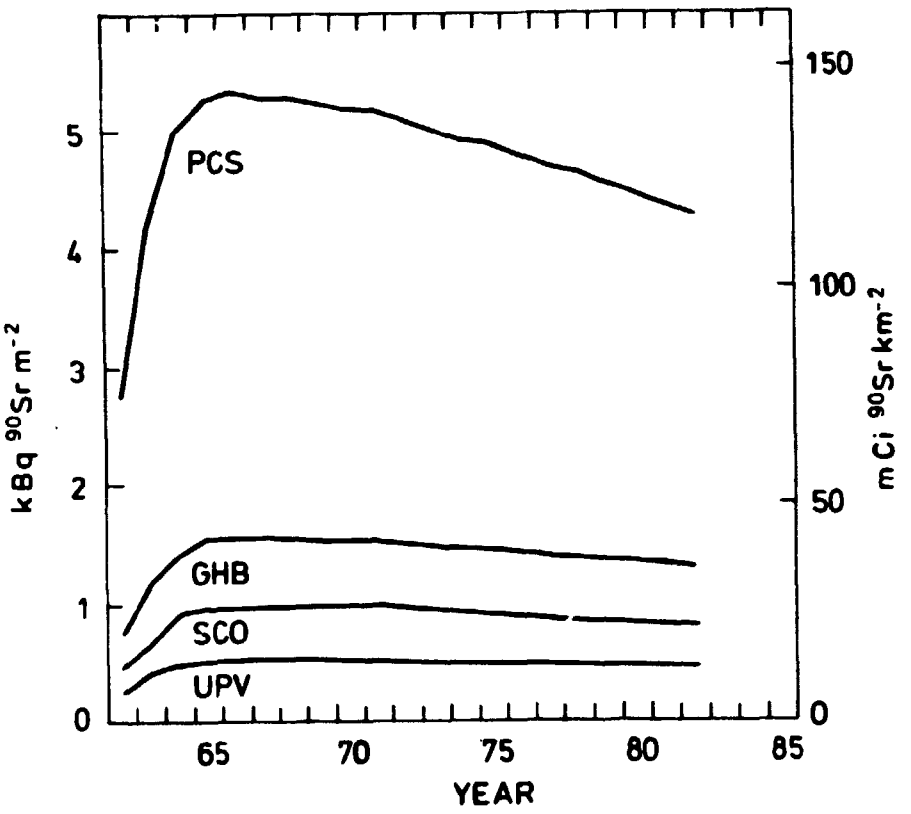

Fig. 2.1. Accumulated ^{90}Sr at Prins Chr. Sund, Godthåb, Scoresbysund (Kap Tobin) and Upernavik calculated from precipitation measurements since 1962. The accumulated fallout by 1962 was estimated from the Danish data (cf. Risø Report No. 447[2]), Appendix D) and from the ratio between the ^{90}Sr fallout at the Greenland stations and the fallout in Denmark in the period 1962-1982.

2.2. Radionuclides in sea water

There were three sampling cruises to Greenland waters in 1982. From Feb. 18-27 HMS Fylla collected ten 50-l surface water samples on its way to East Greenland from Denmark. From July 17 - August 14 the Fishery Investigations of Greenland (GFU) collected surface seawater samples on their cruise with the RV Dana from Denmark to West Greenland. Finally, we were on board M/S Nella Dan in August 1982 and collected surface sea water from Denmark to East Greenland and along the East Greenland coast (cf. Appendix B). In Table 2.2 we report all results from samples collected west of 10°W in 1982. The results of samples from the North Atlantic east of this latitude are found in Risø-R-488[3]. Furthermore, Table 2.2 contains two sea water samples collected by local people in Danmarkshavn and in Angmagssalik.

Table 2.2. Sea water samples collected at Greenland in 1982 (west of 10°W)

Lattitude N	Longitude W	^{3}H kBq m^{-3}	^{90}Sr	^{134}Cs Bq m^{-3}	^{137}Cs	$^{239,240}Pu$ mBq m^{-3}	^{241}Am	Salinity in o/oo	Temp. in °C	Date	Cruise	Station No. at cruise	Remarks
76°50'	18°29'	4.4	6.9	-	6.1	-	-	29.3	-	Nov	Danmarkshavn	colected by local people	
74°59'	18°22'	7.0	-	w/	5.3	16.1	4.4	29.9	1.5	Aug 13	Nella Dan	56,57	
74°55'	13°36'	-	-	e/	6.9	13.4	0.4	29.4	-1.0	Aug 17	- " -	58,59	
74°42'	16°00'	4.1	-	e/	6.1	8.6	0.6	29.8	-1.0	Aug 19	- " -	60,61	
74°29'	15°52'	2.6	-	e/	6.4	18.0	1.1	30.2	-1.5	Aug 20	- " -	62,63	
74°19'	20°14'	4.1	-	w/	5.5	16.1	1.1	30.1	0.5	Aug 9	- " -	52,53	
74°00'	19°49'	4.4	-	w/	5.3	11.2	-	26.9	1.0	Aug 8	- " -	44,45	
72°27'	21°21'	4.4	-	-	5.8	15.3	2.1	27.6	-	Aug 7	- " -	42,43	
72°13'	17°05'	2.2	-	e/	8.1	17.0	1.3	31.1	1.0	Aug 21	- " -	64,65	
70°35'	21°16'	4.4	-	w/	5.2	-	-	31.2	-0.3	Aug 7	- " -	41	
70°22'	21°53'	-	-	-	5.2	19.2	0.7	28.4	-0.5	Aug 24	- " -	66,67	
70°02'	21°08'	3.3	-	w/	5.6	11.5	-	29.4	2.0	Aug 5	- " -	35,36	
69°53'	20°01'	3.9	5.3	-	6.0	-	-	30.4	1.0	Aug 5	- " -	34	
69°40'	19°09'	3.5	7.2	-	6.7	-	-	30.3	1.0	Aug 5	- " -	33	
69°28'	20°03'	3.0	-	e/	6.1	11.1	2.4	30.6	-0.5	Aug 25	- " -	68,69	
69°21'	18°02'	3.6	6.3	-	6.9	-	-	30.2	0.5	Aug 5	- " -	32	
69°05'	17°01'	1.7	4.1	-	7.6	-	-	30.3	0.5	Aug 4	- " -	31	
68°52'	55°16'	2.0	4.2	-	5.3	-	-	33.0	5.6	Aug 6	Dana	17	
68°49'	58°12'	1.9	4.3	-	4.6	-	-	31.4	3.2	Aug 7	"	18	
68°48'	15°59'	1.7	3.4	-	7.7	-	-	30.6	1.0	Aug 4	Nella Dan	30	
68°45'	18°05'	1.4	-	-	7.6	-	-	31.3	1.5	Aug 25	- " -	70	
68°25'	55°29'	1.1	-	-	5.8	-	-	32.8	6.6	Aug 4	Dana	14	
68°25'	15°10'	1.5	-	-	5.0	8.4	1.8	34.5	5.5	Aug 4	Nella Dan	28,29	
68°21'	57°32'	1.3	-	-	4.9	-	-	32.6	3.8	Aug 5	Dana	16	
68°18'	57°13'	1.5	-	-	5.0	-	-	32.6	5.2	Aug 4	"	13	
68°12'	56°26'	1.5	-	-	4.5	-	-	32.2	4.8	Aug 5	"	15	
68°04'	15°59'	1.8	3.5	-	5.8	-	-	34.3	5.0	Aug 25	Nella Dan	71	
67°27'	14°34'	-	-	-	4.0	14.9	1.8	34.4	7.0	Aug 26	- " -	72,73	
66°16'	12°03'	1.7	3.1	-	4.6	-	-	34.2	7.0	Aug 26	- " -	74	
65°36'	37°41'	1.7	5.5	-	6.4	-	-	28.8	-	Oct	Angmagssalik	collected by local people	
65°25'	10°06'	-	-	-	4.4	17.2	2.2	34.5	7.0	Aug 26	Nella Dan	75,76	
65°10'	37°13'	0.9	2.0	-	2.9	-	-	35.2	-	Feb 27	Fylla		
65°03'	27°07'	1.1	2.2	-	2.8	-	-	35.3	-	Feb 28	- " -		
64°31'	35°58'	0.9	2.5	-	3.9	-	-	34.9	-	Feb 27	- " -		
64°02'	52°13'	1.7	4.2	-	6.3	-	-	32.5	7.8	Jul 20	Dana	12	
63°27'	31°32'	2.2	2.0	-	3.6	-	-	35.4	-	Feb 20	Fylla		
63°11'	52°17'	1.1	-	-	6.8			32.4	1.8	Jul 20	Dana	11	
62°49'	52°23'	1.8	-	-	6.4	22.4	2.4	32.7	1.7	Jul 20	"	10	
62°04'	52°36'	1.1	-	-	5.8			33.0	5.1	Jul 20	"	9	
61°19'	38°08'	1.1	1.9	-	2.7	-	-	35.4	-	Feb 27	Fylla		
60°25'	14°50'	1.5	2.5	-	3.6	-	-	35.1	13.8	Aug 14	Dana	20	
60°17'	31°02'	1.5	-	-	4.1	43.9	-	34.8	14.9	Jul 17	"	1	
60°09'	49°29'	0.9	3.0	-	3.9	-	-	33.6	5.4	Jul 19	"	8	
60°09'	52°53'	1.5	-	-	4.3	-	-	35.0	11.0	Jul 18	"	2	
60°09'	25°22'	1.3	2.5	-	3.1	-	-	34.8	12.4	Aug 13	"	19	
59°52'	35°30'	0.9	3.0	-	3.8	-	-	34.5	10.9	Jul 18	"	3	
59°29'	38°26'	0.7	2.4	-	3.2	-	-	34.4	10.0	Jul 18	"	4	
59°12'	40°11'	0.7	2.7	-	3.3	-	-	34.4	8.6	Jul 18	"	5	
58°42'	42°01'	0.9	2.6	-	2.8	-	-	34.5	7.2	Jul 19	"	6	
58°22'	44° 06'	0.6	2.2	-	3.5	-	-	34.5	8.1	Jul 19	"	7	

The ^{134}Cs mean content of the five stations w/ was 0.012±0.005 Bq m^{-3} and the mean concentration of the five stations e/ was 0.043±0.006 Bq m^{-3} (±1 S.D. due to counting statistics.

All samples were analysed for ^{137}Cs (Fig 2.2.1.). We notice that the concentrations in the eastern branch of the East Greenland Current are higher than those close to the East Greenland coast. We found ^{134}Cs in the eastern samples, which show that effluents from Sellafield have entered the East Greenland Current in 1982. These investigations were described elsewhere[7]. Low ^{137}Cs concentrations were observed in the Denmark Strait between Iceland and Greenland. This is ascribed to the influx of Atlantic water from the south by the Irminger Current. It is interesting to notice the relatively high concentrations at the Greenland west coast (cf. below).

The ^{90}Sr concentrations (cf. Fig 2.2.2.) are higher in the East Greenland Current than in the open ocean. Between 68°N and 70°N the ^{90}Sr level increases by about about a factor of two from 15°W to 20°W. If we divide the ^{90}Sr data into two groups of equal size and calculate the $^{137}Cs/^{90}Sr$ ratios of each we find that the mean ratio of the 13 locations closest to the Greenland Coast is 1.20±0.06 (±1 S.E.), while the mean ratio of the other 12 locations is 1.55±0.09 (±1S.E.). The difference between the two ratios was significant at a 99.5% confidence level. Hence we conclude that the East Greenland Current is relatively depleted with respect to ^{137}Cs. If the current gets a substantial part of its ^{137}Cs and ^{90}Sr as runoff from the Siberian rivers to the Arctic Ocean we would expect a lower $^{137}Cs/^{90}Sr$ ratio than observed in open ocean water and in fallout, because ^{137}Cs is attached to clayish sediment particles, which again means that runoff is depleted with respect to ^{137}Cs (cf. also Appendix B). A few $^{137}Cs/^{90}Sr$ ratios are higher than expected in fallout. Most of these ratios were found in samples collected between 16°W and 17°W at 68°N to 69°N. We assume that these samples may have contained traces of radiocesium from Sellafield.

Enhanced concentrations of tritium was observed in the northern part of the East Greenland Current (Fig. 2.2.3). The lowest tritium levels were seen in the Atlantic water south of Kap Farvel. The $^{137}Cs/^{3}H$ ratio increased when we move southward with the East Greenland Current. At Danmarkshavn it is 1.39×10^{-3}, at Scoresbysund: 1.54×10^{-3}, at Angmagssalik: 3.76×10^{-3}, at Godthaab (west coast): 3.71×10^{-3} and Egedesminde

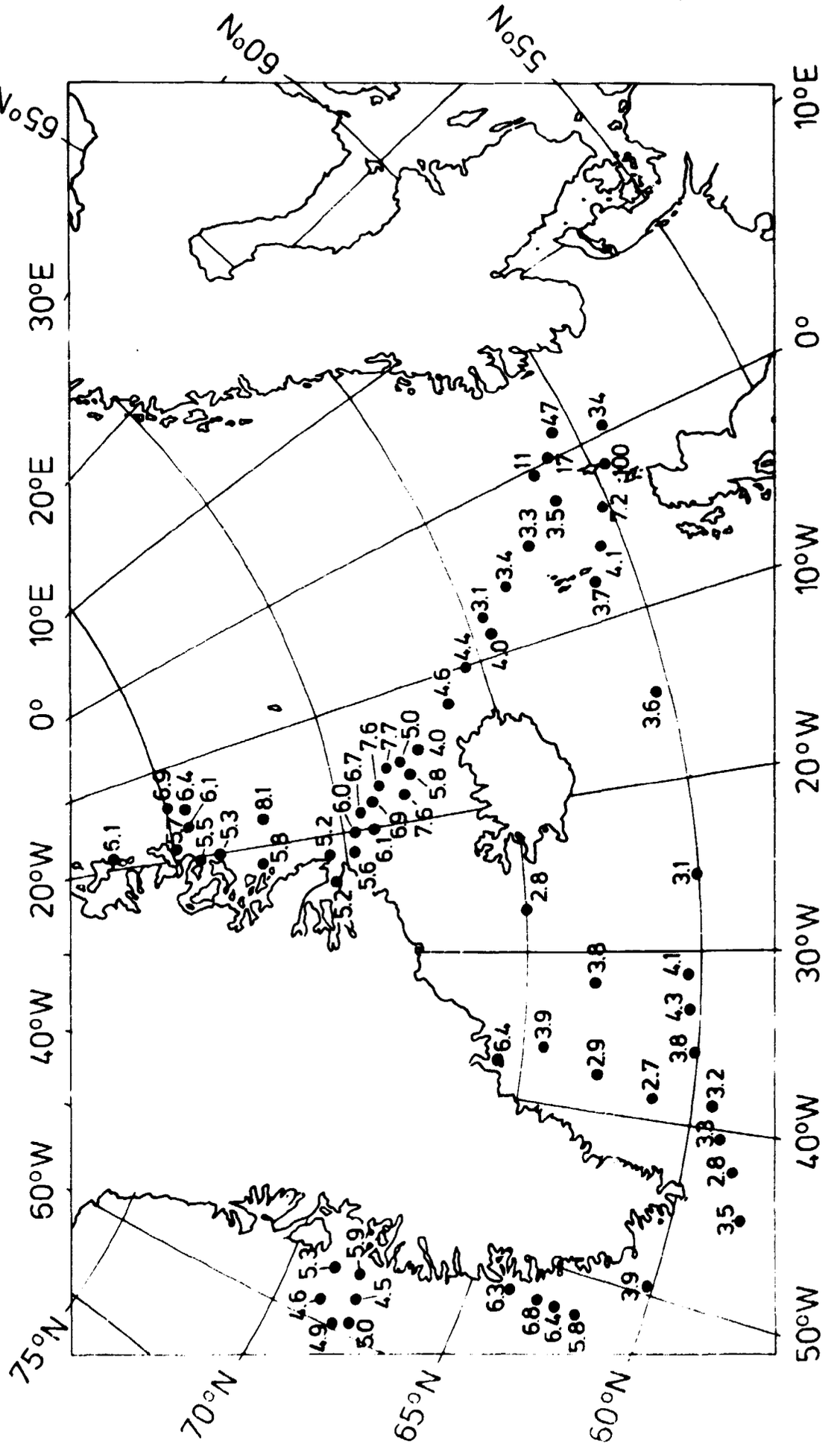

Fig. 2.2.1. Cesium-137 in surface sea water collected in 1982. (Unit: Bq m^{-3}).

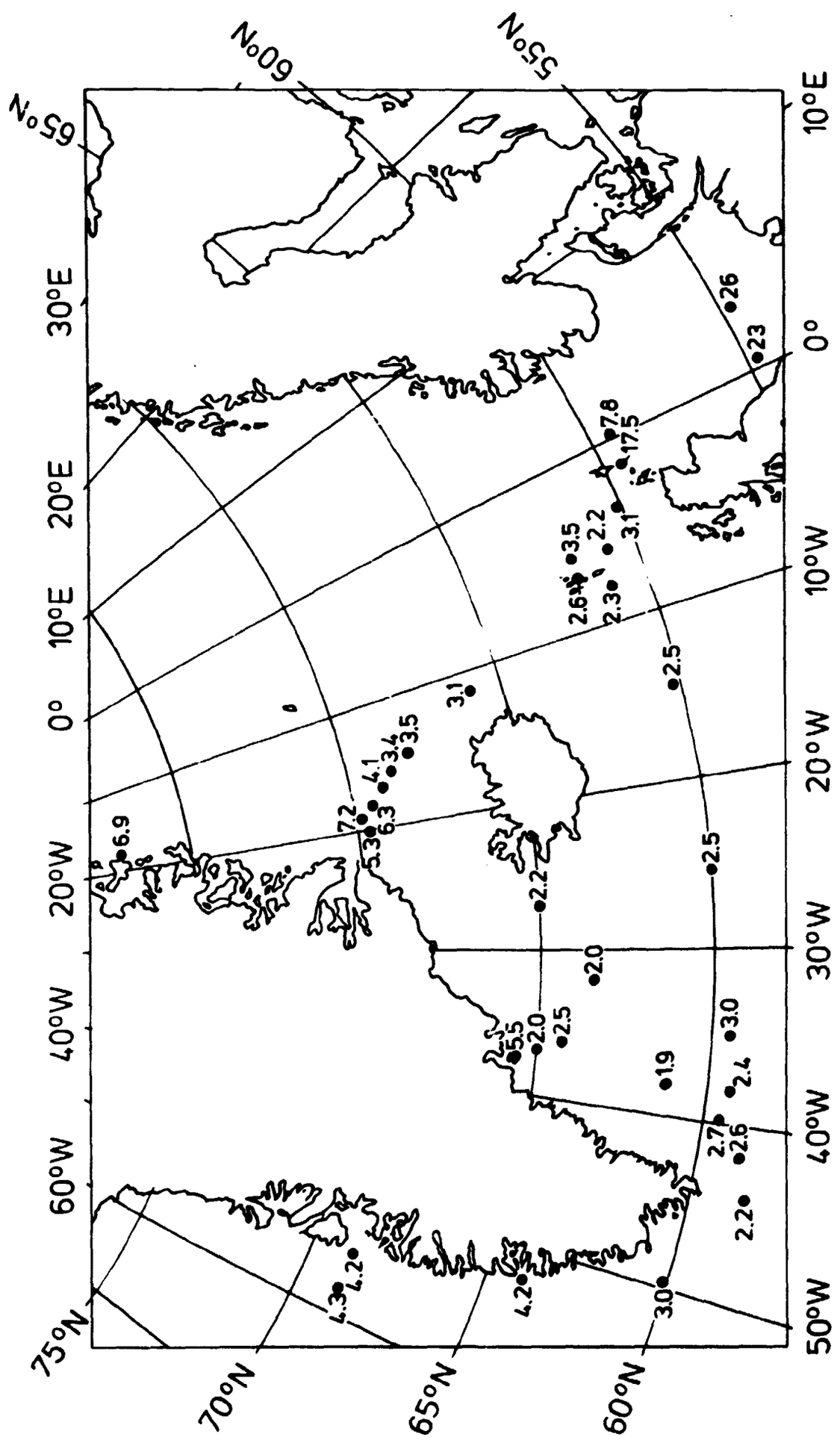

Fig. 2.2.2. Strontium-90 in surface sea water collected in 1982. (Unit: Bq m^{-3}).

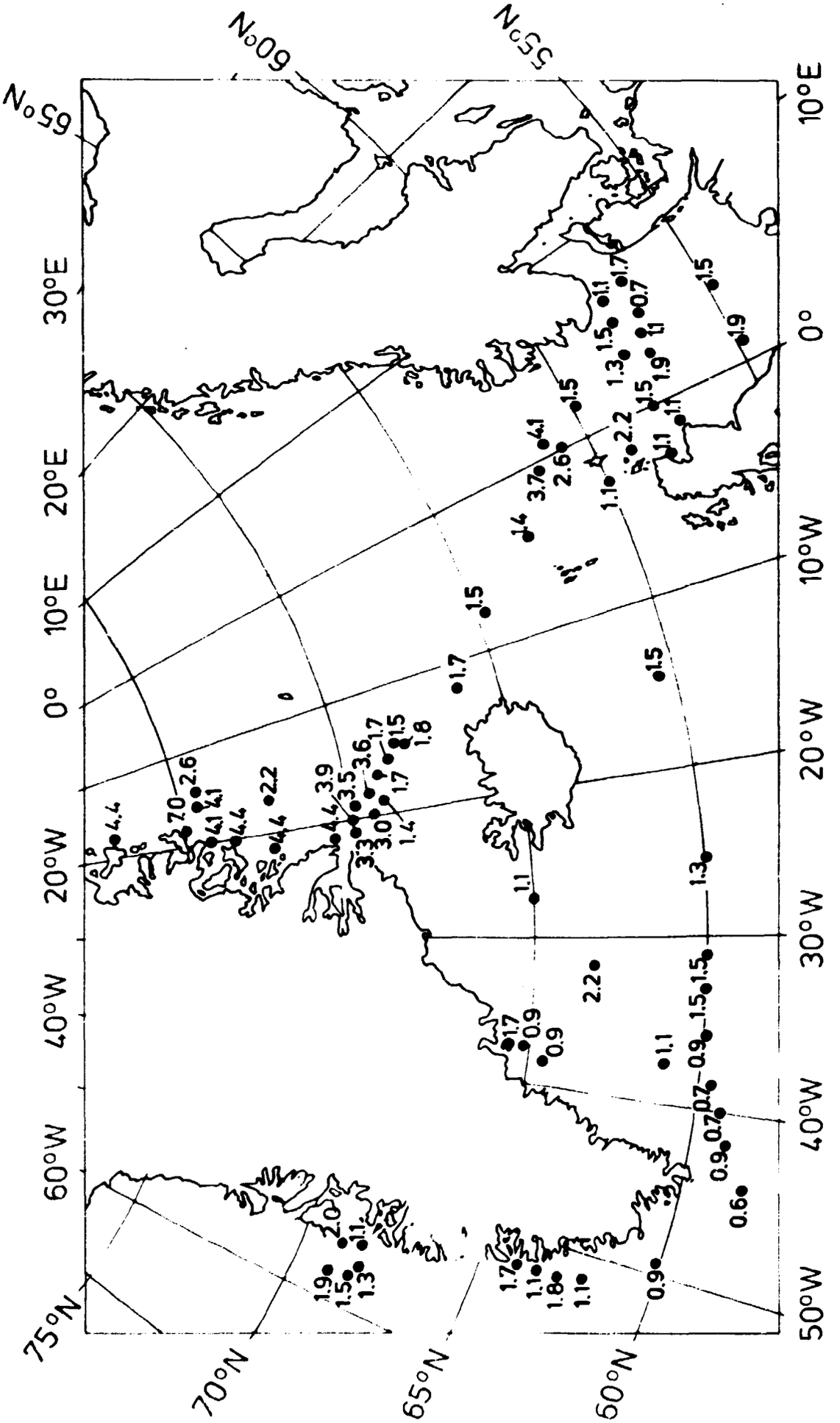

Fig. 2.2.3. Tritium in surface sea water collected in 1982. (Unit: kBq m^{-3}).

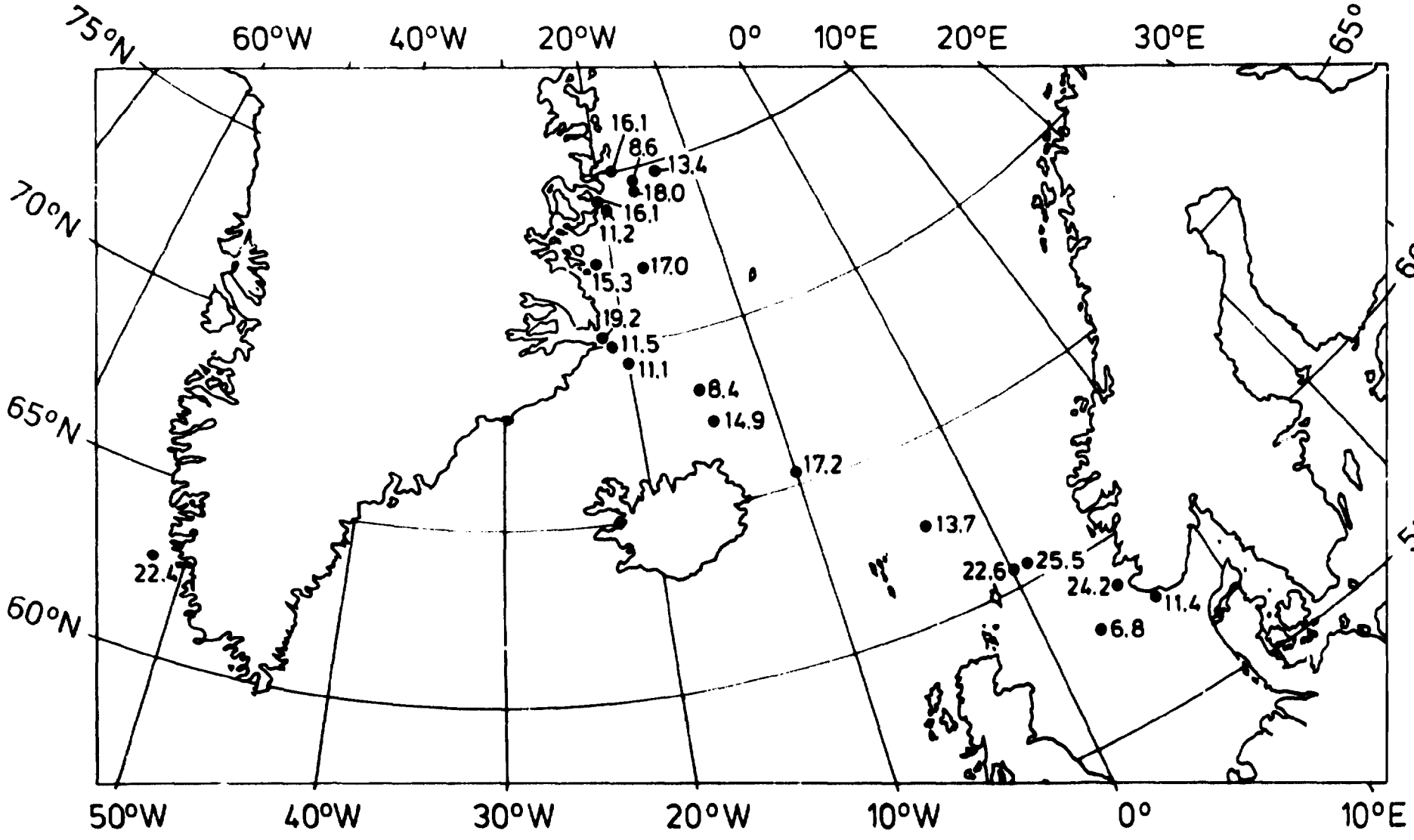

Fig. 2.2.4. Plutonium-239,240 in surface sea water collected in 1982. (Unit: mBq m^{-3}).

(west coast): 2.65×10^{-3}. We can offer one explanation for this observation: The relatively high ^{137}Cs content in the water at Godthaab (62^{o}-$63^{o}N$) may be due to a contribution of Sellafield effluent carried with the East Greenland Current. This parcel of water may have contained higher ^{137}Cs concentrations than the water samples obtained from the east coast; but before the parcel has entered the west Greenland waters, it has been diluted with some low-activity Atlantic water carried by the Irminger Current. This has incidentally lowered the ^{137}Cs concentration to the same level as seen in the samples from the East Coast. The tritium concentration has been lowered even more, however, because the $^{137}Cs/^{3}H$ ratio is higher in the Atlantic than in the Arctic water.

The $^{239,240}Pu$ mean concentrations (Fig. 2.2.4) were about 13 mBq m^{-3} in the East Greenland waters. This is the same level as observed in the Greenland and Barents Seas at the Ymer expedition in 1980[9]. We could observe no significant difference between the Pu-levels in the western and the eastern branch of the East Greenland Current as we did for ^{137}Cs[7]. The ^{241}Am determinations are encumbered with greater uncertainty than the Pu measurements. The observed mean $^{241}Am/^{239,240}Pu$ mean ratio of the 13 determinations were 0.13 ± 0.09 (± 1 S.D.), i.e., the same as observed at the Ymer expedition[9].

2.3. Strontium-90 and Cesium-137 in terrestrial animals

Musk ox and reindeer samples were obtained from Greenland in 1982. The mean levels in musk ox meat were 0.21 Bq ^{90}Sr kg^{-1} and 2.68 Bq ^{137}Cs kg^{-1}. Since 1979[1] when we last time got musk ox the ^{90}Sr level has decreased by a factor of two and the ^{137}Cs level by a factor of 1.5.

The samples of reindeer showed mean levels of 0.19 Bq ^{90}Sr kg^{-1} meat, 83 Bq ^{137}Cs kg^{-1} meat and in bone: 3125 Bq ^{90}Sr $(kg\ Ca)^{-1}$.

These concentrations were higher than those observed in 1979 (and also in 1981). The reindeer samples from Holsteinsborg contained 4 times more ^{137}Cs than those from Egedesminde.

Table 2.3. Strontium-90 and Cesium-137 in terrestrial animals in Greenland in 1982

Date	Location	Sample type		Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$
Aug	Scoresbysund	Musk ox meat	I			2.9	1070
"	- " -	"	II	0.21	1530	3.1	880
"	- " -	"	III			2.3	820
"	- " -	"	IV			2.4	610
	Holsteinsborg	Reindeer meat	I	0.26	4800 (3300)	140	42000
	- " -	"	II	0.198	2200 (5200)	130	33000
	Egedesminde	"	I	0.137	1660 (1900)	31	8280
	- " -	"	II	0.159	4500 (2100)	32	9500

Bone levels are shown in brackets.

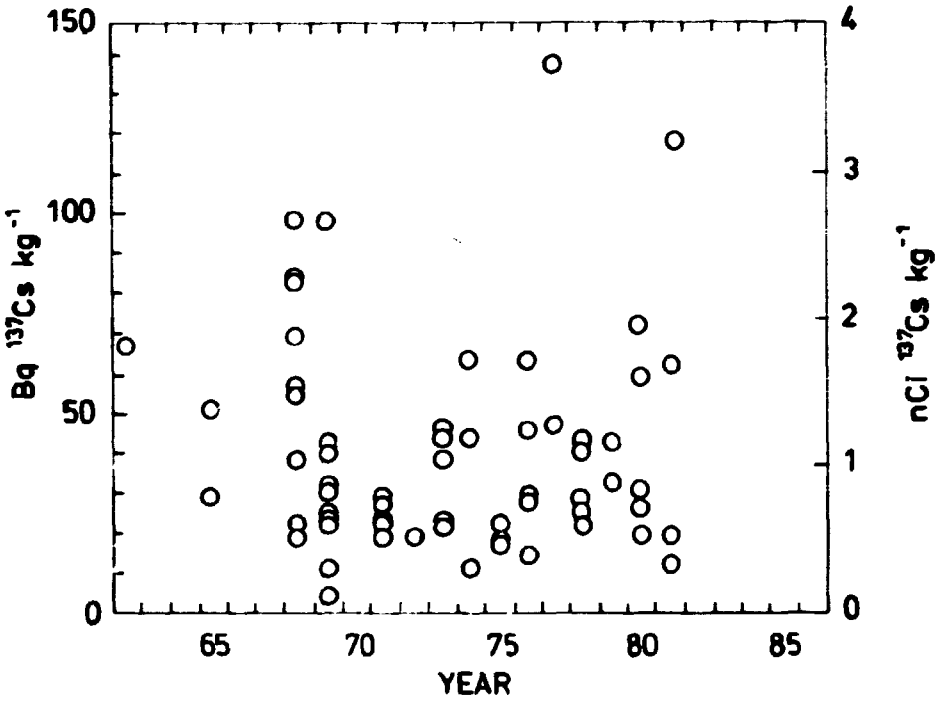

Fig. 2.3.1. Cesium-137 in mutton, 1962-1982. (No samples in 1982).

2.4. Strontium-90 and Cesium-137 in sea animals

The mean levels in cod meat were: 0.006 Bq ^{90}Sr kg^{-1}, 0.36 Bq ^{137}Cs kg^{-1}, and seal contained ~ 0 Bq ^{90}Sr kg^{-1} meat and 0.51 Bq ^{137}Cs kg^{-1}. The mean levels in shrimps were 0.048 Bq ^{90}Sr kg^{-1} flesh and 0.095 Bq ^{137}Cs kg^{-1}. Whale meat contained ~ 0 Bq ^{90}Sr kg^{-1} and 0.75 Bq ^{137}Cs kg^{-1}. Seal bone contained approximately 1 Bq ^{90}Sr (kg Ca)$^{-1}$.

Table 2.4.1. Strontium-90 and Cesium-137 in sea animals collected in Greenland in 1982

Date	Location	Sample	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$
June	Egedesminde	Whale meat I	0.0063	200	0.65	230
"	- " -	" " II	B.D.L.	B.D.L.	0.85	260
	Scoresbysund	Seal meat	B.D.L.	B.D.L. (3.0)	0.99	330
	Egedesminde	" "	B.D.L.	B.D.L. (1.56)	0.54	171
	Sukkertoppen	" " I	0.005 A	41 A (0.5 B)	0.68	240
	- " -	" " II	B.D.L.	B.D.L. (1.3 B)	0.29	114
	Angmagssalik	" " I	B.D.L.	B.D.L. (B.D.L.)	0.25	93
	- " -	" " II	B.D.L.	B.D.L. (B.D.L.)	0.30	156
	Jacobshavn	Cod meat	0.0062	124	0.36	106
	- " -	Shrimps flesh	0.048	56	0.095	77
	Angmagssalik	Angmasatter total	0.0162	7.2	0.24	75
	Egedesminde	" meat	0.008 A	9.4 A(5.0 A)	0.193	57

Bone levels are shown in brackets.

2.5. Radionuclides in vegetation

A fucus sample was obtained from Scoresbysund in August (Table 2.5.1). This sample was collected by local people and may be compared with those collected by us at the east coast in 1982 (cf. Appendices A and B). It is remarkable that the $^{144}Ce/^{137}Cs$ ratio is 3.7 only, in the present sample, while it was 13±6 (1 S.D., N = 7) in the other ones, The $^{137}Cs/^{90}Sr$ ratio is 6.5 compared with 1.8±1.0 (1 S.D., N = 5). Hence the ^{137}Cs concentration was higher than expected in the present sample.

The terrestrial samples in Table 2.5.2 may be compared with those in Tables A.4 and B.3. The $^{144}Ce/^{137}Cs$ ratio in moss from Scoresbysund was 0.22; the mean ratio of the samples in Tables A.4 and B.3 was 0.045±0.016 (1 S.D., N = 11), i.e. much lower. The $^{125}Sb/^{144}Ce$, $^{54}Mn/^{144}Ce$ and $^{106}Ru/^{144}Ce$ ratios were, however, in accordance with those found in a moss sample from Angmagssalik in 1982 (Table A.4). We must thus conclude that the ^{137}Cs content was typically low in the Scoresbysund moss sample.

The lichen sample from Egedesminde showed similar radionuclide levels as the lichen samples from the east coast in Tables A.4 and B.3.

Table 2.5.1. Radionuclides in Fucus collected at Scoresbysund in August 1982

Isotope	Bq kg^{-1} dry weight	rel. S.D. due to counting
^{90}Sr	1.1	6%
^{106}Ru	9.6	21%
^{137}Cs	7.1	3%
^{144}Ce	26	5%

The dry matter content was 14%. The sample contained 40 g K kg^{-1} dry matter and 30 g Ca kg^{-1} dry matter.

Table 2.5.2. Radionuclides in vegetation collected in 1982 in Greenland. (Unit: Bq kg^{-1} dry).

Species	Lichen	Moss	Grass	Grass
Date	June	Aug	8/9	Aug
Location	Egedesminde	Scoresbysund	Egedesminde	Scoresbysund
K *	13.0	3.7	15.9	15.3
Ca *	3.2	8.0	5.0	2.8
^{54}Mn		0.59 B	0.30 B	
^{90}Sr	164	82	14.1	13.4
^{106}Ru		14 A		
^{125}Sb	17 A	4.5		
^{137}Cs	909	72	48	11.9
^{144}Ce	43 A	23	6.6	

* g kg^{-1} dry weight

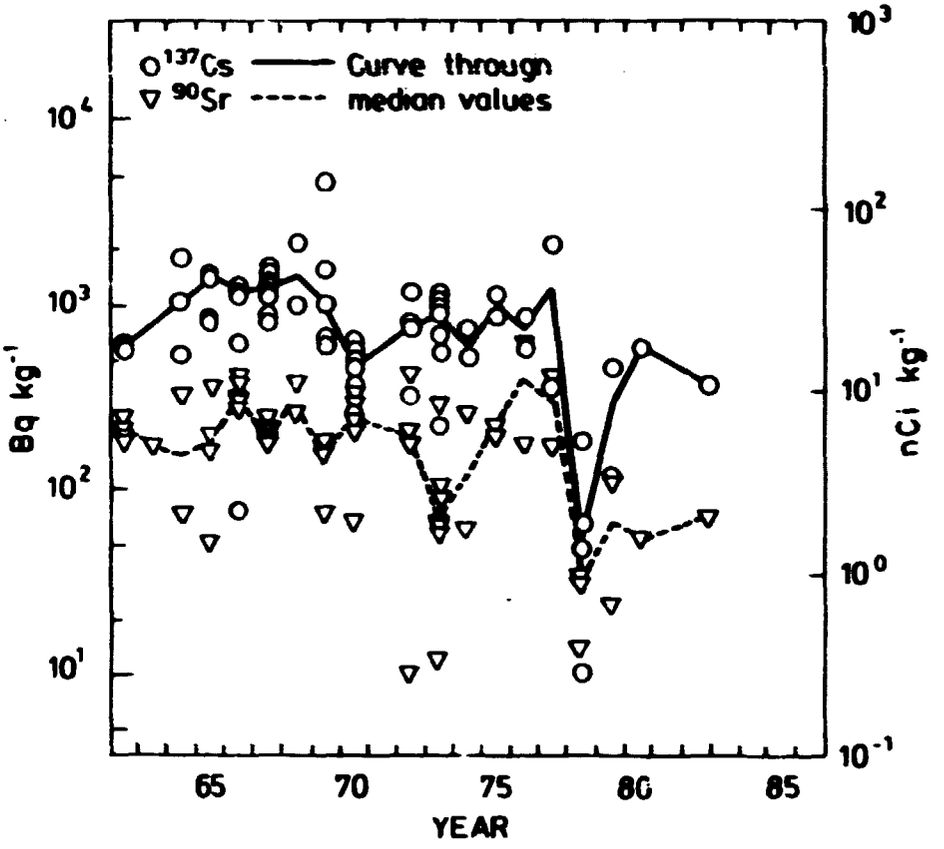

Fig. 2.5. Cesium-137 and Strontium-90 in lichen (fresh weight) collected along the Greenlandic coast, 1962-1982.

2.6. Strontium-90 in drinking water

Quarterly samples of drinking water were collected from a number of locations in Greenland. Table 2.6.1 shows the results from 1982, and Fig. 2.6 the geometric annual means of all samples for the period 1962-1982.

As in previous years, we found it most expedient to choose the geometric mean of all figures, i.e. 20 Bq ^{90}Sr m^{-3} (0.53 pCi l^{-1}) as representative of the mean level of ^{90}Sr in Greenland drinking water in 1982, this level was lower than that observed in 1981, but in agreement with the previous years (Fig. 2.6). The levels in drinking water are still surprisingly high as compared to present rain concentrations (cf. Table 2.1.1). We have suggested that evaporation from the drinking water reservoirs was responsible for the higher ^{90}Sr levels. Tritium measurements show (Table 2.6.2) that the Greenland drinking

water shows similar tritium levels as rain from Denmark[2], hence evaporation seems to be a possible explanation. The high ^{90}Sr levels may, however, also be due to extraction of old deposited ^{90}Sr activity from the soil by the water collected for drinking. This would also be compatible with "normal" tritium concentrations.

Table 2.6.1. Strontium-90 in drinking water collected in Greenland in 1982. (Unit: Bq m^{-3})

Location	Jan-March	April-June	July-Sept	Oct-Dec
Danmarkshavn	56	16.7	18.0	36
Prins Chr. Sund	50	16.6	9.8	
Scorebysund	18.0	36	8.8	9.0
Godthåb			12.1	

Table 2.6.2. Tritium in drinking water collected in Greenland in 1982. (Unit: kBq m^{-3})

Location	Jan-March	July-Sept
Danmarkshavn	5.7±0.2	
Prins Chr. Sund	4.3±0.2	
Scorebysund	4.8±0.4	
Godthåb		4.1±0.0

The error term is 1 S.E. of the mean of double determinations.

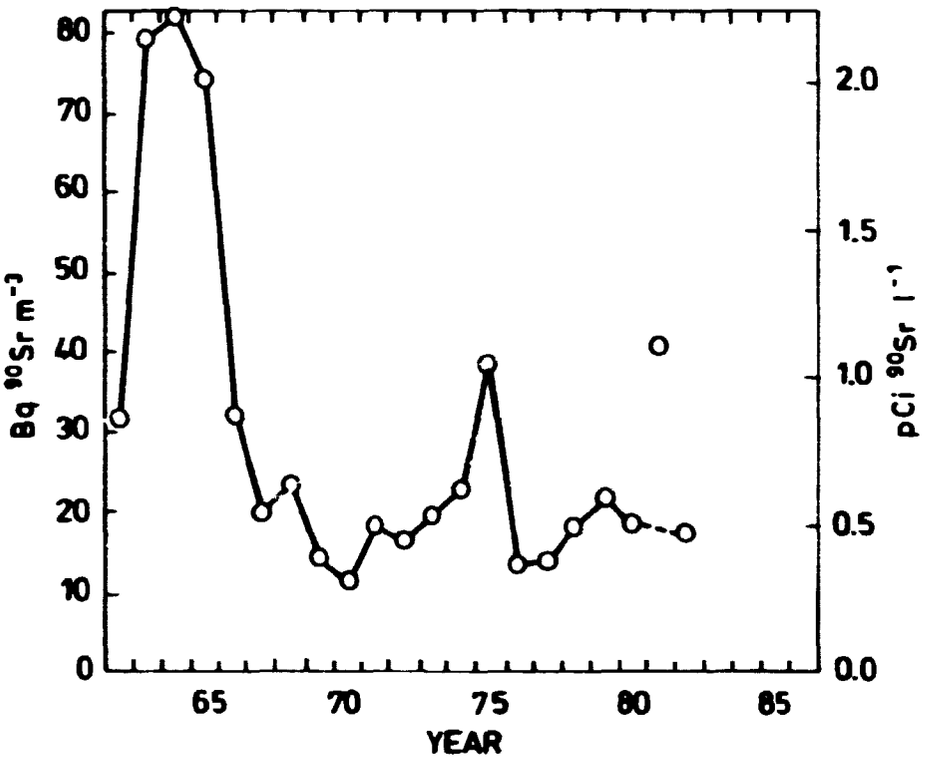

Fig. 2.6. Strontium-90 in Greenlandic drinking water (Geometric mean), 1962-1982.

3. ESTIMATE OF THE MEAN CONTENTS OF ^{90}Sr AND ^{137}Cs IN THE HUMAN DIET IN GREENLAND IN 1982

3.1. The annual quantities

The estimate of the daily per capita intake of the different foods in Greenland is still based on the figures given in 1962 by the late Professor E. Hoff-Jørgensen, Ph.D., in Risø Report No. 65[1].

3.2. Milk products

All milk consumed in Greenland was imported as milk powder from Denmark. The mean radioactivity content in milk prepared from Danish dried milk produced in 1982 was 0.122 Bq ^{90}Sr kg^{-1} and 0.105 Bq ^{137}Cs kg^{-1} [2].

Cheese was also imported from Denmark and contained 0.87 Bq ^{90}Sr kg^{-1} and 0.076 Bq ^{137}Cs kg^{-1}.

3.3. Grain products

All grain was imported from Denmark. It is assumed that only grain from the harvest of 1981 was consumed in Greenland during 1982. The daily per capita consumption was: rye flour (100% extraction): 80 g, wheat flour (75% extraction): 110 g, rye flour (70% extraction): 20 g, biscuits (rye, 100% extraction): 27 g, and grits: 25 g. The content of ^{90}Sr in these five products was 1.10, 0.16, 0.22, 0.81 and 0.35 Bq kg^{-1} respectively. Hence the mean content of ^{90}Sr in grain products was 0.54 Bq kg^{-1}. The content of ^{137}Cs in the five products was 1.52, 0.28, 0.76, 1.13 and 0.27 Bq kg^{-1}. Hence the mean content of ^{137}Cs in grain products was 0.78 Bq kg^{-1}.

The activity levels in rye flour (100% extraction), wheat flour (75% extraction), and grits were all taken from Tables 5.9.1 and 5.9.2 in Risø Report No. 487[2]. The ^{90}Sr level in rye flour (70% extraction) was calculated analogously with the level in wheat flour (75% extraction), i.e. as one-fifth of the whole-grain activity. The ^{137}Cs content in rye flour (70% extraction) was calculated as one half of the whole-grain level in rye in analogy with the ratio between ^{137}Cs in whole wheat grain and in wheat flour (75% extraction)[2]. The ^{90}Sr and ^{137}Cs contents in biscuits were calculated by dividing the levels of the rye flour (100% extraction) by 1.35, since 1 kg flour yields 1.35 kg bread[2].

3.4. Potatoes, other vegetables, and fruit

The Danish mean levels for 1982 were used[2] since the local production is insignificant compared with imports from Denmark.

The Danish mean levels were: in potatoes 0.065 Bq ^{90}Sr kg^{-1} and 0.063 Bq ^{137}Cs kg^{-1}, in other vegetables 0.32 Bq ^{90}Sr kg^{-1} and 0.053 Bq ^{137}Cs kg^{-1}, and in fruit 0.054 Bq ^{90}Sr kg^{-1} and 0.038 Bq ^{137}Cs kg^{-1}.

3.5. Meat

Nearly all meat consumed in Greenland is assumed to be of local origin. Approx. 10% comes from sheep, 5% from reindeer, 60% from seals, 5% from whales, and 20% from sea birds and eggs.

The activities in lamb (1981 data) and reindeer were estimated from 2.3. Seal and whale were estimated from 2.4. The levels of sea birds and eggs were taken from the 1978 analyses[1]. Hence the mean levels in Greenland meat from 1982 were 0.039 Bq ^{90}Sr kg^{-1} and 1?.16 Bq ^{137}Cs kg^{-1}.

(^{90}Sr: $0.1 \times 0.28 + 0.05 \times 0.19 + 0.6 \times \sim 0 + 0.05 \times 0.003 + 0.2 \times 0.007 = 0.039$ Bq kg^{-1})

(^{137}Cs: $0.1 \times 66 + 0.05 \times 83 + 0.6 \times 0.51 + 0.05 \times 0.75 + 0.2 \times 0.35 = 11.16$ Bq kg^{-1})

3.6. Fish

All fish consumed was of local origin, and the mean levels (cod and Angmasetter meat) from 2.4 were used, i.e. 0.007 Bq ^{90}Sr kg^{-1} and 0.28 Bq ^{137}Cs kg^{-1}.

3.7. Coffee and tea

The Danish figures for 1982[2] were used for coffee and tea, i.e. 0.87 Bq ^{90}Sr kg^{-1} and 2.53 Bq ^{137}Cs kg^{-1}.

3.8. Drinking water

The geometric mean calculated in 2.6 was used as the mean level of ^{90}Sr in drinking water, i.e. 20 Bq ^{90}Sr m^{-3}. The ^{137}Cs content was as previously[1] estimated at 1/4 of the ^{90}Sr content, i.e approx. 5 Bq ^{137}Cs m^{-3}.

Tables 3.1 and 3.2 show the diet estimates of ^{90}Sr and ^{137}Cs respectively.

Table 3.1. Estimate of the mean content of ^{90}Sr in the human diet in Greenland in 1982

Type of food	Annual quantity in kg	Bq ^{90}Sr per kg	Total Bq ^{90}Sr	Percentage of total Bq ^{90}Sr in food
Milk and cream	78	0.122	9.52	10.9
Cheese	2.5	0.87	2.18	2.5
Grain products	95.6	0.54	51.62	58.7
Potatoes	32.8	0.065	2.13	2.4
Vegetables	5.5	0.32	1.76	2.0
Fruit	13.5	0.054	0.73	0.8
Meat and eggs	45.6	0.039	1.78	2.0
Fish	127.6	0.007	0.89	1.0
Coffee and tea	7.3	0.87	6.35	7.2
Drinking water	548	0.02	10.96	12.5
Total			87.92	

The mean annual calcium intake is estimated to be 0.56 kg (approx. 0.2-0.25 kg creta praeparata). Hence the $^{90}Sr/Ca$ ratio in Greenland total diet in 1982 was 157 Bq ^{90}Sr (kg Ca)$^{-1}$ or 4.2 pCi ^{90}Sr (g Ca)$^{-1}$ and the daily intake was 0.24 Bq ^{90}Sr or 6.5 pCi ^{90}Sr.

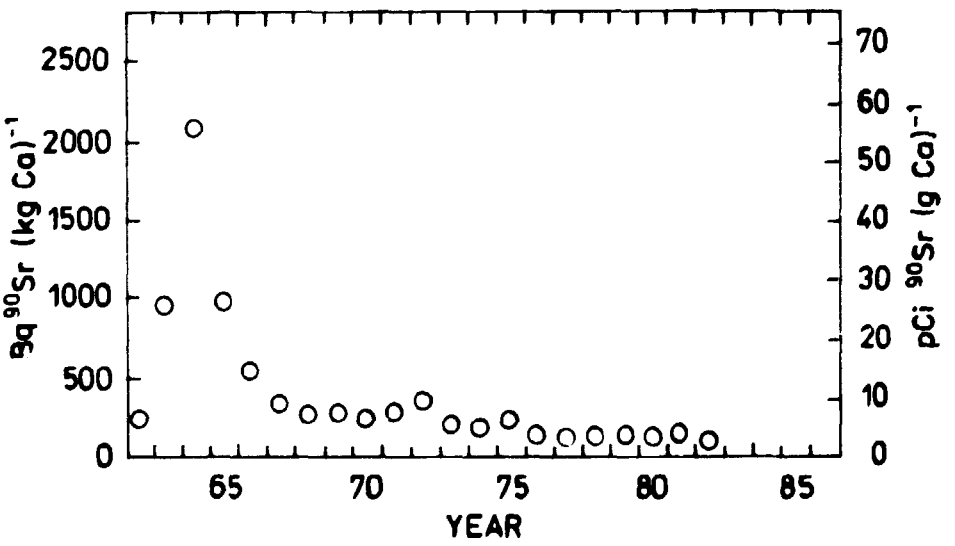

Fig. 3.1. Strontium-90 in Greenlandic diet, 1962-1982.

Table 3.2. Estimate of the mean content of ^{137}Cs in the human diet in Greenland in 1982

Type of food	Annual quantity in kg	Bq ^{137}Cs per kg	Total Bq ^{137}Cs	Percentage of total Bq ^{137}Cs in food
Milk and cream	78	0.105	8.19	1.3
Cheese	2.5	0.076	0.19	0.0
Grain products	95.6	0.78	74.57	11.4
Potatoes	32.8	0.063	2.07	0.3
Vegetables	5.5	0.053	0.29	0.1
Fruit	13.5	0.038	0.51	0.1
Meat and eggs	45.6	11.16	508.90	78.1
Fish	127.6	0.28	35.73	5.5
Coffee and tea	7.3	2.53	18.47	2.8
Drinking water	548	0.005	2.74	0.4
Total			651.66	

The mean annual potassium intake is estimated to be approx. 1.2 kg. Hence the $^{137}Cs/K$ ratio becomes 543 Bq ^{137}Cs $(kg\ K)^{-1}$ or 14.7 pCi ^{137}Cs $(g\ K)^{-1}$. The daily intake in 1982 from food was 1.79 Bq ^{137}Cs or 48 pCi ^{137}Cs.

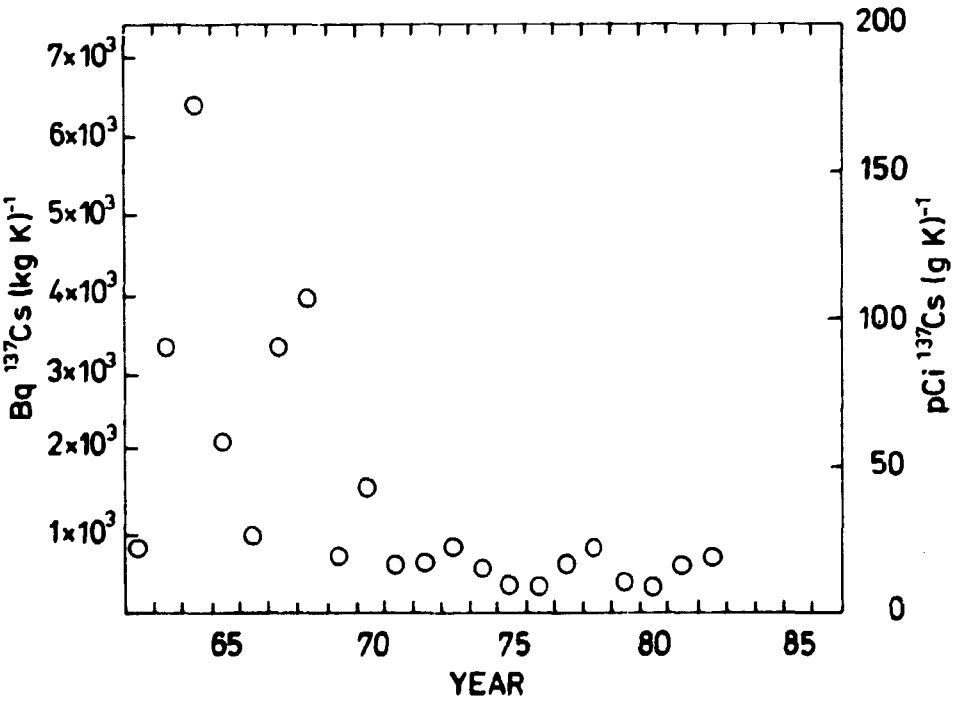

Fig. 3.2. Cesium-137 in Greenlandic diet, 1962-1982.

3.9. Discussion

The most important ^{90}Sr source in the Greenland diet is still grain products, which contribute 59% of the total ^{90}Sr content in the diet. Approx. 85% of the ^{90}Sr in the food consumed in Greenland in 1982 originated from imported (Danish) food.

Meat is still the most important ^{137}Cs source in the Greenland diet, contributing 78% of the total content in 1982. Approx. 85% of the ^{137}Cs in the Greenland diet in 1982 came from local products.

As compared with the 1981 figures, the ^{90}Sr contents in the total diet in 1982 was nearly unchanged.

The ^{137}Cs level was 23% higher than the level found in 1981. As earlier discussed[1] the great variations from year to year are primarily due to the variations in the ^{137}Cs levels in the meat samples obtained.

To estimate the maximum per capita intakes of ^{90}Sr and ^{137}Cs in Greenland in 1982 we assume[1] that the only grain product consumed by a person is dark rye bread, and that he only eats reindeer meat. His daily intake of ^{90}Sr is thus 0.40 Bq and his ^{137}Cs intake 11.0 Bq day^{-1} (using the quantities in Tables 3.1 and 3.2). At the lower limit we can imagine a person eating white bread and seal and drinking water with hardly any activity (e.g. water formed by the melting of old ice). In this case the daily intakes are 0.11 Bq ^{90}Sr and 0.32 Bq ^{137}Cs. Hence the ratios between the levels in the maximum and minimum diets become 4 for ^{90}Sr and 34 for ^{137}Cs.

The ^{90}Sr content of the Greenland diet in 1982 was 94% of the estimated Danish mean content[2], and 65% of the Faroese level[3]. The ^{137}Cs level in the total diet in Greenland was 4.2 times that of the Danish diet and 34% of the Faroese diet level.

4. CONCLUSION

4.1.

The ^{90}Sr fallout rates in 1982 were the following: Prins Chr. Sund: approx. 6.4 Bq ^{90}Sr m^{-2}; Godthåb: aprox. 2.6 Bq m^{-2}; Scoresby Sund: 2.4 Bq m^{-2}; Upernavik: 1.6 Bq ^{90}Sr m^{-2} and Danmarkshavn: 2.0 Bq m^{-2}. The accumulated fallout levels by the end of 1982 were estimated at approx. 1010 Bq ^{90}Sr m^{-2} at Godhavn, 1250 Bq ^{90}Sr m^{-2} at Godthåb, 4420 Bq ^{90}Sr m^{-2} at Prins Chr. Sund, and 445 Bq ^{90}Sr m^{-2} at Upernavik.

4.2.

The food consumed in Greenland in 1982 contained on the average 157 Bq ^{90}Sr (kg Ca)$^{-1}$, and the daily mean intake of ^{137}Cs was estimated at 1.79 Bq. The most important ^{90}Sr contributor to the diet were grain products accounting for approx. 60% of the total ^{90}Sr content of the diet. Cesium-137 originated mainly from meat (reindeer and lamb) and fish, contributing approx. 85% of the total ^{137}Cs content of the diet.

4.3.

No ^{90}Sr analyses of human bone samples have hitherto been carried out on the population of Greenland. Considering the estimated ^{90}Sr levels in the diet, it seems probable[4], however, that the 1982 ^{90}Sr levels of humans in Greenland were on the average rather similar to those found in Denmark, i.e. the mean levels in human bone in Greenland were approx. 30 Bq ^{90}Sr (kg Ca)$^{-1}$ (vertebrae). From diet measurements the ^{137}Cs content in Greenlanders was estimated at 1600 Bq ^{137}Cs (kg K)$^{-1}$.

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APPENDIX A

Environmental samples collected in July 1982 at Angmagssalik

In connection with the sampling in the East Greenland Current between 69°N and 75°N in August 1982 (cf. Appendix B) we wanted also to have some samples further south. We selected Angmagssalik at 65°35'N, as a convenient location. Our intention was to obtain marine as well as terrestrial samples. We have on earlier occasions observed unexpectedly high levels in samples from East Greenland[1]. We therefore wanted to see, by personal inspection, if we could observe special environmental circumstances which could explain the abnormalities.

Another purpose of this expedition was to test a new field method for collecting large-column sea water samples. We used 100-l plastic bags suspended under a phototripod. The water was carried to the bags in 10-l plastic buckets. We filled two plastic bags, one for radiocesium, which we precipitated with AMP; and one for Pu, precipitated by NaOH. The two bags stayed the night over and the supernatant was sucked off by a syphon. The precipitate was collected in 10-l bottles. Before the final shipment the AMP precipitate was transferred to a 200-ml bottle (cf. also Appendix D).

Table A.1 shows the results of the sea water analysis from Angmagssalik. At location 3 (cf. Fig. A.1) the water was nearly fresh and the concentrations of ^{137}Cs and $^{239,240}Pu$ are thus untypical for sea water. At location 1 the concentrations are comparable with those from the Greenland east coast shown in Table 2.2 in the main text.

We collected seaweed (fucus and laminaria) from four locations. Due to the tide the fucus plants are frequently exposed to the air and this may influence the activity levels, especially for the shorter-lived radionuclides. The ^{144}Ce concentrations in

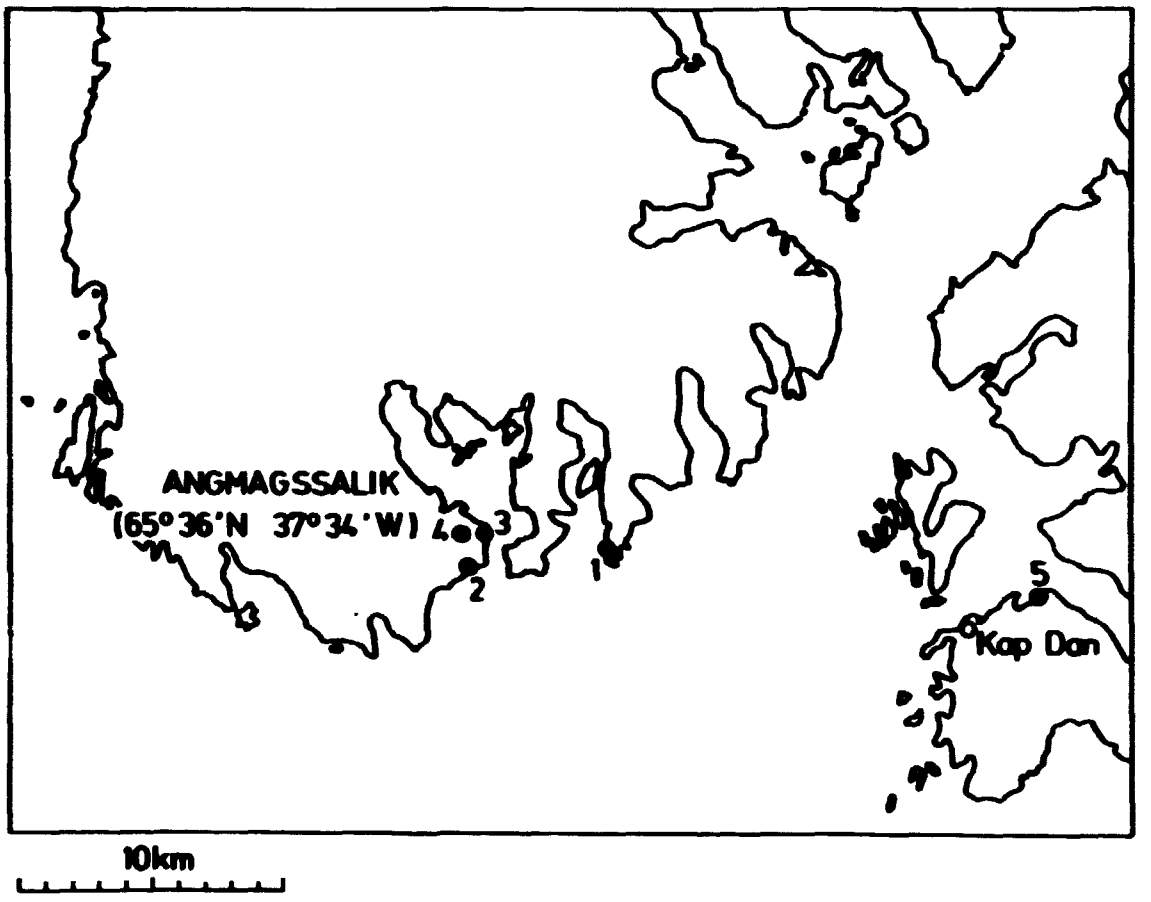

Fig. A.1. Sampling locations in Angmagssalik in July 1982.

Table A.1. Sea water collected at Angmagssalik in July 1982. Bq m^{-3}

	Location 1 July 16	Location 3 July 18
^{137}Cs	5.3 ±0.2	2.1 ±0.2
$^{239,240}Pu$	0.017±0.002	0.033±0.003
Salinity	21 o/oo	3.8 o/oo

The error term is 1 S.D. due to counting statistics.

fucus are remarkable. In 1978 (cf. Risø-R-405, Table 2.5)[1], we found approximately 90 Bq ^{144}Ce kg^{-1} dry weight in fucus collected at Angmagssalik and at Scoresby Sund, i.e. approximately twice as much as in the present samples. We suppose that the main source of ^{144}Ce in 1978 as well as in 1982 has been fresh airborne debris from Chinese test explosions containing ^{144}Ce (and other fallout nuclides). The ^{144}Ce fallout in 1978 was actually twice that in 1982.

Mussels were found at location 1 (cf. Fig. A.1). From Tables A.3 and A.1 we may estimate the concentration ratios for Bq Kg^{-1} mussel flesh (dry weight)/Bq l^{-1} sea water. In the case of ^{137}Cs we get:

$$\frac{0.64}{5.3 \times 10^{-3}} = 121$$

For $^{239,240}Pu$:

$$\frac{0.028}{0.017 \times 10^{-3}} = 1.6 \times 10^{3}$$

For the shells the ratio becomes:

$$0.6 \times 10^{3}$$

In 1981 at the Faroes and Iceland (cf. Risø-R-470)[3], we found a concentration ratio for ^{137}Cs in mytilus of 113 and for Pu of 1.6×10^{3}; the present ratios are thus in agreement with these earlier observations.

The terrestrial samples from Angmagssalik consisted of lichen and moss collected on a plateau (location 4 in Fig. A.1). The moss sample differed from three of the lichen samples. The concentrations of the various fallout radionuclides were an order of magnitude higher in the moss. We assume that this sample has collected runoff from an area larger than it is actually covering. The radiocesium and the transuranics especially were retained efficiently in the moss, whereas ^{90}Sr

Table A.2. Fucus vesiculosus (f) and Laminaria (l) collected in Angmagssalik in July 1982. (Bq kg^{-1} dry weight).

	Location 1 Stations Nos. 3 & 4 July 16 (f)	Location 2 Station No. 7 July 17 (f)	Location 3 Station No. 12*) July 18 (f)	Location 5 Station No. 16 July 19 (f)	Location 1 Station No. 6 July 17 (l)
^{7}Be	97 ±1	534 ±2	456 ±2	157 ±2	33 ±2
^{54}Mn	0.72 ±0.12	1.29 ±0.09	2.1 ±0.1	1.02 ±0.15	-
^{90}Sr	1.29 ±0.11*	2.8 ±0.2*	4.6 ±0.1*	1.19 ±0.14*	0.66 ±0.14
^{95}Zr	-	3.09 ±0.17	1.0 ±0.1	-	-
^{95}Nb	-	2.8 ±0.1	6.0 ±1.2	-	-
^{99}Tc	7.4 ±0.4	8.7 ±0.4	0.2 ±0.2	9.4 ±0.5	30 ±1.5
^{106}Ru	4.0 ±1.1	14.9 ±0.9	23 ±1	10.4 ±1.4	-
^{125}Sb	-	1.8 ±0.2	1.3 ±0.2	1.4 ±0.3	-
^{137}Cs	1.03 ±0.10	3.1 ±0.1	2.7 ±0.1	2.7 ±0.1	1.6 ±0.3
^{144}Ce	18.2 ±0.6	54 ±1	55 ±1	33 ±1	8.6 ±1.2
^{238}Pu	0.05 ±0.02*	-	0.062 ±0.004*	-	-
$^{239,240}Pu$	0.63 ±0.02*	0.74 ±0.13*	1.09 ±0.00*	0.36 ±0.02*	0.16 ±0.01*
^{241}Am	0.073 ±0.0.0		0.088 ±0.009	-	-
^{40}K g kg^{-1}	25.9 ±0.1	28.4 ±0.1	38.7 ±0.1	31.8 ±0.2	7.3 ±0
Salinity	21 o/oo	~ 4 o/oo	3.8 o/oo	30 o/oo	21 o/oo
fresh w / dry w	3.88	4.86	5.31	3.99	7.70

*) ^{60}Co at station 12: 0.26 ±0.08 Bq kg^{-1} dry weight.

*1 S.E. of the mean of double determinations.
In all other cases the error term is 1 S.D. due to counting statistics.

Table A.3. Mytilus edulis collected at Angmagssalik (location 1) July 17, 1982. (Bq kg^{-1} dry weight).

	Flesh	Shell
^{7}Be	31 ±3	-
^{137}Cs	0.64 ±0.02	-
^{226}Ra	-	2.2 ±0.5
$^{239,240}Pu$	0.028 ±0.003	0.010 ±0.002
fresh w / dry w	3.54	1.01

The error term is 1 S.D. due to counting statistics.

Table A.4. Moss and Lichen collected at Angmagssalik in July 1982

Sample		^{7}Be	^{54}Mn	^{60}Co	^{90}Sr	^{95}Nb	^{106}Ru	^{125}Sb	^{137}Cs	^{144}Ce	^{238}Pu	$^{239,240}Pu$	^{241}Am	q H/kg dry w.	Fresh w./dry w.
Lichen	Bq kg^{-1} dry w.							2,711,1	1331	5,811,7	0,09910,008	2,0910,02	0,6310,03	4,5	1,23
loc.4 st.10	Bq m^{-2}							38 112	1430110	83 119	1,1	23	6,8		
Lichen	Bq kg^{-1} dry w.	60117							7131 5	41 18	0,37 10,03	5,5010,05	2,3 10,1	5,1	1,60
loc.4 st.11	Bq m^{-2}	125							1500110	135 123	0,6	11,7	4,9		
Lichen	Bq kg^{-1} dry w.	15 14							1741 1	6,812,5	0,00810,000	2,2110,02	0,7510,05	3,8	1,33
loc.4 st.13	Bq m^{-2}	170140							1950116	77 128	0,9	25	8,4		
Moss*)	Bq kg^{-1} dry w.	660 33	4,3 10,9	3,5 10,8	137 125*	4,5 10,8	120 14	44 15	3350 16	230 16	2,0 10,1*	60 10*	13,8 10,2	3,1	1,84
loc.4 st.14	Bq m^{-2}	2800 152	18 4	14 3	580	19 1	490 180	180 121	13800 44	960 140	8,2	247	57		
Lichen	Bq kg^{-1} dry w.	42 14			177 17*				1758 5	87 15	0,29 10,01	9,5 10,1	3,1 10,1	4,7	1,28
loc 4 st.15	Bq m^{-2}	210 77			1230				8488 27	478 126	1,6	51	17		

*) S.E. of the mean of double determinations.

In all other cases the error term is 1 S.D. due to counting statistics.

*)This sample also contained 8 Bq ^{207}Bi kg^{-1} dry weight.

does not seem to be enriched. In this moss sample we also found some less-abundant fallout nuclides such as ^{60}Co and ^{207}Bi[6]. The lichen sample from station 15 also showed enhanced concentrations of ^{137}Cs and Pu and Am. This sample may also have collected some runoff. If we assume the 3 lichen samples (st. 10, st. 11 and st. 13) to be "normal", i.e. representing the fallout from the area they cover only, we may estimate the accumulated ^{137}Cs fallout at 1630 Bq m^{-2} (44 mCi km^{-2}) and the $^{239,240}Pu$ fallout at 20 Bq m^{-2} (0.53 mCi km^{-2}). From the measurements of fallout in Greenland[1] and from the amount of precipitation in Angmagssalik (~ 990 mm per year). We estimate the true amount of ^{137}Cs fallout to be 2400 Bq m^{-2} (65 mCi km^{-2}) and the $^{239,240}Pu$ fallout to be 57 Bq m^{-2} (1.5 mCi km^{-2}). Hence the lichen samples underestimate the accumulated ^{137}Cs fallout by a factor of 1.5 and the Pu fallout by a factor of 3 (cf. also Table B.4). The $^{238}Pu/^{239,240}Pu$ mean ratio was 0.040±0.008 (1 S.D., N = 5) and the $^{241}Am/^{239,240}Pu$ ratio was 0.32±0.07 (1 S.D., N = 5). Both ratios are in accordance withs those observed in accumulated fallout in the Northern hemisphere.

In conclusion, although we have observed enhanced concentrations in some samples, marine as well as terrestrial, we think that all observations are compatible with what was to be expected from global airborne fallout.

APPENDIX B

Environmental samples collected during the "Nella Dan expedition" to East Greenland in August 1982

From August 1 to 27 we (Dahlgaard and Hallstadius) were on board the M/S Nella Dan, hired by the Royal Greenland Trade Company as supply ship for the Greenland East Coast. During the cruising from Denmark to Scoresby Sund in East Greenland and up along the east coast to Shannon Island at approximately 75°N, surface sea water samples were collected. The ship's pump brought the water up from a depth of approximately 3 m. Fifty litres as well as 200-l samples were obtained. The 200-l samples were processed on board either with an AMP precipitation for radiocesium determination or with a NaOH precipitation for Pu and Am analyses. The 50-l samples were brought home for ^{137}Cs, ^{90}Sr and ^{3}H analysis (cf. also Appendix D). The results of the seawater sampling were presented in Table 2.2.

At Scoresby Sund and at Daneborg we collected fucus and some terrestrial samples (Tables 3.1 and 3.3, respectively). The fucus samples contained similar levels as those from Angmagssalik (cf. Table A.2), however, the ^{144}Ce contents were lower. We suppose that this may be due to a shorter period of aerial exposure at the Northern stations due to a longer period of ice cover and to diminished tide. From the water concentrations in Tables 2.2 and A.1 and from the fucus concentrations in Tables A.2 and B.1 we may calculate the concentration ratios between fucus (Bq kg^{-1} dry weight) and sea water (Bq l^{-1}) as shown in Table B.2. If we compare these with the mean results obtained for samples from the Faroe Islands and Iceland in 1981[3], we notice that the present ratio for Pu was nearly an order of magnitude higher than that observed in 1981 ($(0.46 \pm 0.33) \times 10^4$), while the ^{137}Cs ratio was a little lower (in 1981: 260±70). From the laminaria sample from Angmagssalik we notice that the Pu concentration ratio is nearly four times lower than that for fucus, while ^{137}Cs shows a higher concentration ratio for laminaria than for fucus.

Table B.1. Radionuclides in fucoids collected at Scoresbysund and Daneborg in August 1982. (Bq kg^{-1} dry weight)

	Daneborg 74°19'N 20°15'W Nella Dan st. 46	Scoresbysund 70°25'N 21°57'W Nella Dan st. 37
^{54}Mn	-	1.10 ±0.25
^{137}Cs	0.84 ±0.19	1.11 ±0.19
^{144}Ce	8.9 ±1.3	8.7 ±1.3
$^{239,240}Pu$	0.52 ±0.03	0.86 ±0.03
^{241}Am	0.077 ±0.015	0.059 ±0.015
g K/kg	27 ±0.2	42 ±0.2
$\frac{\text{fresh weight}}{\text{dry weight}}$	4.97	5.21
Salinity	~ 30 o/oo	~ 30 o/oo

The error term is 1 S.D. due to counting statistics.

Table B.2. Concentrations ratios determined at 3 locations in East Greenland in 1982

	$\frac{\text{Fucus dry weight}}{\text{Sea water}}$ $^{239,240}Pu$	$\frac{\text{Fucus dry weight}}{\text{Sea water}}$ ^{137}Cs
Daneborg 74°19'N 20°15'W	$\frac{0.52}{16.1 \times 10^{-6}} = 3.2 \times 10^4$	$\frac{0.84}{5.7 \times 10^{-3}} = 147$
Scoresbysund 70°25'N 21°57'W	$\frac{0.86}{19.2 \times 10^{-6}} = 4.5 \times 10^4$	$\frac{1.11}{5.2 \times 10^{-3}} = 213$
Angmagssalik 65°36'N 37°41'W	$\frac{0.63}{17 \times 10^{-6}} = 3.7 \times 10^4$	$\frac{1.03}{5.3 \times 10^{-3}} = 194$
$\bar{x}$ ±1 S.D.	$(3.8 \pm 0.7) \times 10^4$	185 ±34
Laminaria from Angmagssalik	$\frac{0.16}{1.7 \times 10^{-6}} = 0.94 \times 10^4$	$\frac{1.6}{5.3 \times 10^{-3}} = 302$

If we use the concentration ratios in Table B.2 and the measured $^{239,240}Pu$ and ^{137}Cs concentrations in fucus and laminaria samples collected in 1969 at Scoresby Sund (cf. Risø-R-471, Appendix A)[1], we may calculate the sea water concentrations in 1969. We find that the Pu concentrations were 8 times higher in 1969 and the ^{137}Cs concentrations 3-4 times higher. In other words, the Pu content in the East Greenland Current has decreased more rapidly than the ^{137}Cs content. There may be two explanations for this: Firstly, Pu is more easily precipitated from the water column than Cs and secondly a new source of Cs (Sellafield effluents) have entered the East Greenland Current recently[7]. The first explanation is the most pertinent. The ^{90}Sr concentration in seawater collected at the east coast (Danmarkshavn and Angmagssalik) in 1968-1970 was 10.4±1.7 Bq m^{-3} (1 S.D., N = 4). The mean concentration at Danmarkshavn and Angmagssalik in 1982 was 6.2±1.0 (1 S.D., N = 2) Bq ^{90}Sr m^{-3}, i.e. only aproximately 2 times lower than in 1969. The dominant source of ^{90}Sr in the East Greenland Current is global fallout. We know that ^{90}Sr has less affinity to sediments than ^{137}Cs (and Pu). Furthermore, we have seen (cf. 2.2.) that the $^{137}Cs/^{90}Sr$ ratio in coastal sea water at Greenland is lower than in fallout and in ocean water. This implies that runoff of ^{90}Sr from the Siberian rivers to the Arctic Ocean is relatively greater that the runoff of ^{137}Cs (and Pu). The ^{90}Sr in the East Greenland Current consequently shows a longer mean residence time than ^{137}Cs, which again disappears more slowly than Pu from the current.

The terrestrial samples in Table B.3 should be compared with those from Angmagssalik in Table A.4. If we use only the lichen samples for an estimate of the accumulated ^{137}Cs fallout, we find 740 Bq m^{-2} (20 mCi km^{-2}) at Scoresby Sund and 155 Bq m^{-2} (4 mCi km^{-2}) at Daneborg. The soil samples from Daneborg suggest that the lichen figures may underestimate the actual level. In 1978[1] lichen and moss samples collected in Danmarkshavn showed 240 Bq ^{137}Cs m^{-2} and 800 Bq ^{137}Cs m^{-2}, respectively. In Table B.4 we have shown an estimate of the accumulated ^{137}Cs fallout at four locations in East Greenland. It had been discussed

Table B.3.1. Cesium-137 and ^{144}Ce in terrestrial samples collected at Scoresbysund and Daneborg in August 1982

	Daneborg: 74°19'N 20°15'W				Scoresbysund: 70°25'N 21°57'W			
	^{137}Cs		^{144}Ce		^{137}Cs		^{144}Ce	
	Bq kg^{-1} dry w.	Bq m^{-2}	Bq kg^{-1} dry w.	Bq m^{-2}	Bq kg^{-1} dry w.	Bq m^{-2}	Bq kg^{-1} dry w.	Bq m^{-2}
Reindeer lichen Nella Dan st. 51,38	360±11	123	25 ±12	8.5	540±20	980	17 ±5	31
Black lichen Nella Dan st. 50,39	770±20	184	63 ±18	15	1830±40	495	85 ±14	23
0-1 cm soil layer Nella Dan st. 47	19±1	350	-	-	-	-	-	-
0-1 cm soil layer Nella Dan st. 48	24±1	310	-	-	-	-	-	-
Moss Nella Dan st. 55,40	180±7	760	4.9±1.4	21	220±7	1490	7.5±3.5	51
Moss spagnum Nella Dan st. 54	150±9	630	-	-	-	-	-	-
Hare excrements Nella Dan st. 49	60±3	-	-	-	-	-	-	-

The error term is 1 S.D. due to counting statistics.

Table B.3.2. Transuranics in terrestrial samples collected at Scoresbysund and Daneborg in August 1982

	Daneborg: 74°19'N 20°15'W				Scoresbysund: 70°25'N 21°57'W			
	$^{239,240}Pu$		^{238}Pu / $^{239,240}Pu$	^{241}Am / $^{239,240}Pu$	$^{239,240}Pu$		^{238}Pu / $^{239,240}Pu$	^{241}Am / $^{239,240}Pu$
	Bq kg^{-1} dry w.	Bq m^{-2}			Bq kg^{-1} dry w.	Bq m^{-2}		
Reindeer lichen Nella Dan st. 51,38	3.7	1.3	0.040	0.43	7.1	13	0.033	0.36
Black lichen Nella Dan st. 50,39	11.4	2.7	-	0.41	12.8	3.5	0.048	0.44
0-1 cm soil layer Nella Dan st. 47	0.38	7.0	0.014	0.35	-	-	-	-
0-1 cm soil layer Nella Dan st. 48	0.34	4.4	-	0.22	-	-	-	-
Moss Nella Dan st. 55,40	4.7	19.7	0.042	0.16	3.3	23	0.032	0.27
Moss spagnum Nella Dan st. 54	1.76	7.4	-	0.34	-	-	-	-
Hare excrements Nella Dan st. 49	0.72	-	0.039	0.36	-	-	-	-

earlier[8] what the true ^{137}Cs fallout was north of Scoresby Sund, where the musk ox is living. Table B.3 shows that both Bq kg^{-1} and Bq m^{-2} decrease as we go north. However, the concentrations decrease less rapidly than the Bq m^{-2} data. This implies that the radioecological sensitivity of lichen and moss and thus also of animals living from these vegetations increase when we move northward. The radioecological sensitivity of musk ox meat from North-East-Greenland was estimated earlier at 0.08 Bq ^{137}Cs y per Bq ^{137}Cs m^{-2} this was based upon fallout data from Scoresby Sund. If the mean ^{137}Cs fallout at Daneborg and Danmarkshavn, as suggested by Table B.4, is three times less than in Scoresby Sund the true radioecological sensitivity for musk ox meat becomes 0.24 Bq ^{137}Cs y per Bq ^{137}Cs m^{-2}.

From Table B.3.2 we may estimate the accumulated $^{239,240}Pu$ at Scoresbysund and Daneborg. We assume that the lichen samples represent 1/3 of the accumulated Pu (cf. Appendix A). Hence we get 25 Bq $^{239,240}Pu$ m^{-2} at Scoresbysund and 6 Bq m^{-2} at Daneborg.

Table B.4. Estimates of accumulated ^{137}Cs in East Greenland based upon lichen samples

Location	Lattitude N	Longitude W	Fallout weighted annual mean precipitation in mm	Bq ^{137}Cs m^{-2} in lichen carpet	Estimated true accumulated ^{137}Cs (correction factor 1.5, cf. text) Bq m^{-2}	Sample year
Danmarkshavn	76°46'	18°46'	110	240	360	1978
Daneborg	74°18'	20°13'	230	155	230	1982
Scoresbysund	70°25'	21°58'	423	740	1100	1982
Angmagssalik	65°36'	37°34'	991	1630	2400	1982

The coordinates in this table are those of the meteorological stations.
The true fallout in Angmagssalik was estimated from the accumulated ^{90}Sr fallout in Godthåb (1255 Bq m^{-2}) assuming a $^{137}Cs/^{90}Sr$ ratio of 1.6 and a mean precipitation in Angmagssalik 1.2 times that in Godthåb: 1255 × 1.6 × 1.2 = 2410. The true accumulated fallout at the other locations was assumed to be proportional with 2410/1630 = 1.5.

APPENDIX C

Brown Algae collected in Greenland in 1969-1970

In Risø-R-471[1] we presented $^{239,240}Pu$ and ^{137}Cs data on fucus and laminaria samples collected by the Geological Survey of Greenland in 1969 and in 1970. Table C.1 shows the ^{90}Sr determinations of these samples. As for $^{239,240}Pu$ and ^{137}Cs the ^{90}Sr data also show some high concentrations. However, as the $^{239,240}Pu/^{90}Sr$ ratios show, there was no correlation between the Pu and ^{90}Sr concentrations.

If we omit the outlines in Table C.1 the concentration ratio for ^{90}Sr in laminaria would be:

$$\frac{6.2 \text{ Bq kg}^{-1} \text{ dry weight}}{10.4 \times 10^{-3} \text{ Bq l}^{-1}} = 6 \times 10^2$$

and for fucus:

$$\frac{3.78 \text{ Bq kg}^{-1} \text{ dry weight}}{10.4 \times 10^{-3} \text{ Bq l}^{-1}} = 3.6 \times 10^2 .$$

In 1982 the ^{90}Sr mean contents in coastal waters along East Greenland was 6 Bq m^{-3}; hence the expected ^{90}Sr concentrations in laminaria and fucus were 3.6 and 2.2 Bq kg^{-1} dry weight. The observed concentrations in fucus at Angmagssalik (Table A.2) and at Scoresby Sund (Table 2.5.1) were in accordance with this prediction, while the observed ^{90}Sr content in laminaria was five times lower than predicted. Thus we may have overestimated the concentration ratio for ^{90}Sr in laminaria.

Table C.1. Strontium-90 in brown algae collected in Greenland in 1969-1970 (cf. Risø-R-471 Appendix A)[1)]

Location		Species	^{90}Sr Bq kg^{-1} dry w.	$\frac{^{239,240}Pu}{^{90}Sr}$	$\frac{^{137}Cs}{^{90}Sr}$	Year	No.
69°56'N	22°30'W	Laminaria	6.2±0.1	0.15	0.82	Aug 1969	285
69°35'N	23°21'W	Laminaria	24.7±0.2	0.038	-	- " -	291
69°44'N	23°05'W	Fucus	2.4±0.1	1.62	-	- " -	287
69°38'N	23°15'W	?	32.1±0.1	-	-	- " -	288
- " -		Fucus	166 ±1	0.025	0.21	- " -	289
- " -		?	5.4±1.1	-	-	- " -	290
71°00'N	25°23'W	Fucus	6.1±0.2	1.38	0.91	Jul 1969	293
70°35'N	22°25'W	Fucus	3.0±0.1	2.06	-	Aug 1969	307
71°33'N	27°48'W	Fucus	3.6±0.1	0.50	-	- " -	317
60°50'N	46°00'W	Fucus	4.1±0.3	0.21	0.76	1970	324
60°59'N	45°50'W	Fucus	4.5±0.2	0.24	-	1970	323

APPENDIX D

Procedure for concentration of radiocesium in large volume sea water samples

1. Aproximately 1800 l of sea water are stirred during 1 hour with 100 g AMP[10].

2. The sample stands overnight over and the supernatant is sucked off.

3. The AMP is transferred to a 25-l bottle and finally filtered on a 5.5-cm filter.

4. This filter is γ-counted by Ge(Li) spectroscopy and the amount of ^{137}Cs is determined.

5. To improve the geometry and to get rid of interferring γ-emitters the sample of AMP may be dissolved and reprecipitated as Cs_2PtCl_6[11].

6. The AMP is transferred to a 1-l beaker.

7. 150 ml H_2O + 350 ml NaOH (240 g NaOH l^{-1}) are added to the AMP.

8. The AMP is dissolved under stirring (pH = 9-10).

9. The solution is filtered on a paper filter and any impurities are kept for γ-counting if wanted.

10. 15-ml Cs-carrier (10 mg Cs ml^{-1}) is added.

11. The pH is adjusted to 7 with HCl. The solution shall be clear.

12. The sample is placed in a refrigerator (0-5^{o}C) for 24 hours.

13. 15 ml H_2PtCl_6 (10% solution) is added under stirring.

14. Stirring for 10 minutes until an orange precipitate has been formed.

15. The beaker with the sample is placed in a refrigerator for 24 hours.

16. The sample is filtered on a 5.5-glassfiber filter.

17. The sample is γ-counted and the $^{134}Cs/^{137}Cs$ ratio is determined if possible.

18. The yield of the AMP precipitation in the 1800-l sample is determined from a 50-l aliquot in which the ^{137}Cs concentration has been determined by AMP precipitation with a ^{134}Cs spike.

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